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Electrical and Optical Response Properties of MEH-PPV Semiconductor Polymer Schottky Diodes

by Fred Semendy, Greg Meissner, and Priyalal Wijewarnasuriya

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14. ABSTRACT
Diodes made with poly(2-methoxy-5(2'-ethyl)hexoxy-phenylenevinylene) (MEH-PPV) using indium tin oxide (ITO) as anode and aluminum (Al) as cathode have been fabricated and investigated for current-voltage (I-V) characteristics and optical responsivity. The diode exhibits non-ideal behavior with ideality factor of 0.85 eV. The I-V characteristics of the ITO/MEH-PPV/Al diode without light and with different illumination intensities give an open circuit voltage (V_{oc}) and a short circuit current of (I_{sc}). This suggests that that this diode is a photovoltaic under light illumination. Variations in the responsivity indicate that the ITO/MEH-PPV/Al device is a photo-sensitive diode.

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MEH-PPV, polymer, diode, Schottky

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Contents

List of Figures

1. Introduction

The usage of soluble conjugate polymers as active materials in optoelectronic applications has opened up the possibility of fabricating many different devices. Soluble conjugated polymers, with their advantage of low cost, flexibility, and high absorption coefficient, have shown the possibility for photodetection and photovoltaic applications. Over the years, the power conversion efficiency has been increasing steadily and rapidly (*1*–*4*). Organic semiconductors have been extensively used in electronic devices as active components. Conjugated polymers, known as organic semiconductors with electronic properties, have a wide application in electronic technology. In the past few years, poly(2-methoxy-5(2'-ethyl)hexoxy-phenylenevinylene) (MEH-PPV) has been considered as one of the potential and useful conducting polymers for various optoelectronic applications, such as sensors and organic solar cells, and organic light emitting diodes (OLED) because of its environmental stability and easy conductivity properties. The MEH-PPV acts as an electron donor (p-type semiconducting polymer) with a relatively low conductivity due to its low hole and electron mobilities when compared to inorganic semiconductor materials (*5*).

The fabrication and characterization of the Schottky diodes using organic semiconductor MEH-PPVs and their derivatives have commanded considerable attention in recent years (*6*, *7*). The device performance of a Schottky diode depends on electrical and electronic characteristics of metal organic semiconductor junction. In this study, an indium-doped tin oxide (ITO)/MEH-PPV/aluminum (Al) Schottky diode was fabricated. The electronic properties, such as barrier height, ideality factor, series resistance, interface properties and the optical response behavior of the diode, are reported.

2. Experimental

The semiconducting polymer MEH-PPV was purchased from Sigma Aldrich Company. The ITO coated on glass substrate was obtained from Merck with a sheet resistance of 20 Ω cm, a thickness of 100 nm, and a transmittance of about 80% in the visible. The ITO substrate was cleaned in an ultrasonic bath of acetone for 20 min, followed by isopropyl alcohol (IPA) rinsing for 20 min at room temperature, before being dried in a nitrogen gas flow. MEH-PPV solutions were prepared in chloroform or 1.2 dichlorobenze solvents separately at a concentration of 15 mg/ml. The solutions were mixed for 2 h by sonicating. Before spin casting the MEH-PPV solution, part of the ITO was masked for future metal contacts for wire bonding. The MEH-PPV solution was spin cast on an ITO/glass plate at 3000 rpm for 40 s. The film was dried at 50 °C for 10 min on a hot plate to evaporate the solvent. Film thickness was measured using a KLA-

Tencor 15 and found to be ~200 nm. The film was immediately placed in CHA e-beam evaporator for the metal deposition. At a vacuum of $2x10^{-6}$ Torr, a 200-nm-thick Al film was deposited on top of the MEH-PPV layer. Figure 1 shows (a) the chemical structure of MEH-PPV and (b) the fabricated MH-PPV diode.

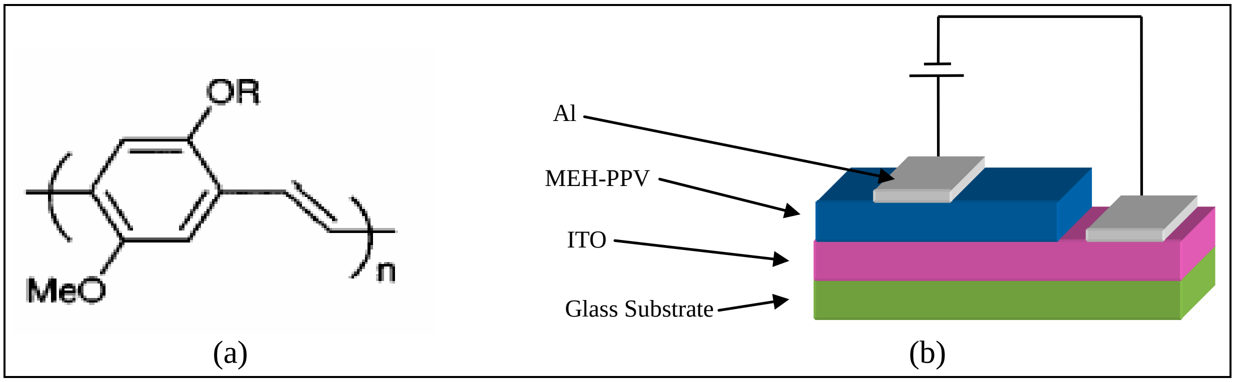

Figure 1. (a) Chemical structure of MEH-PPV and (b) a schematic diagram of ITO/MEH-PPV/Al Schottky diode.

Figure 2 provides the current-voltage (I-V) characteristics of the ITO/MEH-PPV/Al diode.

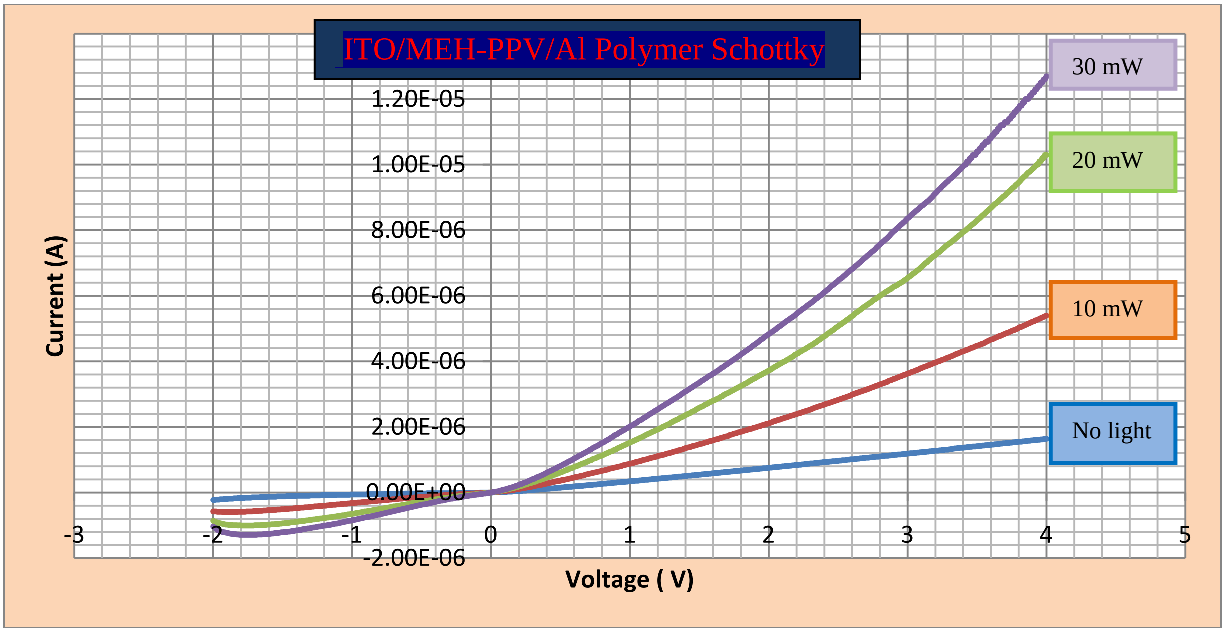

Figure 2. I-V characteristics of a ITO/MEH-PPV/Al Schottky diode.

3. Results and Discussion

I-V measurements shown in figure 2 were made with Agilent 4156 C parametric analyzer. The diode shows a rectifying behavior and the rectification ratio, which is the ratio of the forward current to reverse current at the certain voltage, was found to be 2.22 x 10^5 at ±3 V. The I-V characteristics of the diode can be expressed by the following relation (*7, 8*):

$$I = I_0 \exp\left(\frac{(q(V-IRs)}{nkT}\right) \quad \left[1 - \exp\left(\frac{q(V-IRs)}{kT}\right)\right], \tag{1}$$

where R_s is the series resistance, V is the applied voltage, n is the ideality factor, k is the Boltzmann constant, T is the temperature, and I_0 is the reverse saturation current given by

$$I_0 = AA^{**} T^2 \exp\left(-\frac{q\phi_B}{kT}\right), \tag{2}$$

where ϕ_B is the barrier height and A is the contact area, and A^{**} is the Richardson constant.

The diode indicates a non-ideal behavior due to the series resistance. For low voltages, the diode exhibits a linear behavior, but at higher voltages it deviates due to the series resistance and interface state density. To determine the diode parameters, Cheung's method (*9, 10*) was used to determine the diode's parameters. Cheung's functions are defined as follows:

$$\frac{dV}{dln(I)} = n\frac{kT}{q} + IR_s \tag{3}$$

and

$$H(I) = V - n\frac{kT}{q}\ \ln\left(\frac{I_\circ}{AA^* T^2}\right) = IR_s + n\ \phi_B. \tag{4}$$

The plots of $\frac{dV}{dln(I)}$ versus I are given on figure 3 and show a straight line behavior due to the series resistance region. The series resistance is found to be higher due to the resistance of the polymer MEH-PPV organic semiconductor. The polymeric semiconductor has low mobility and electrical conductivity with respect to an inorganic semiconductor.

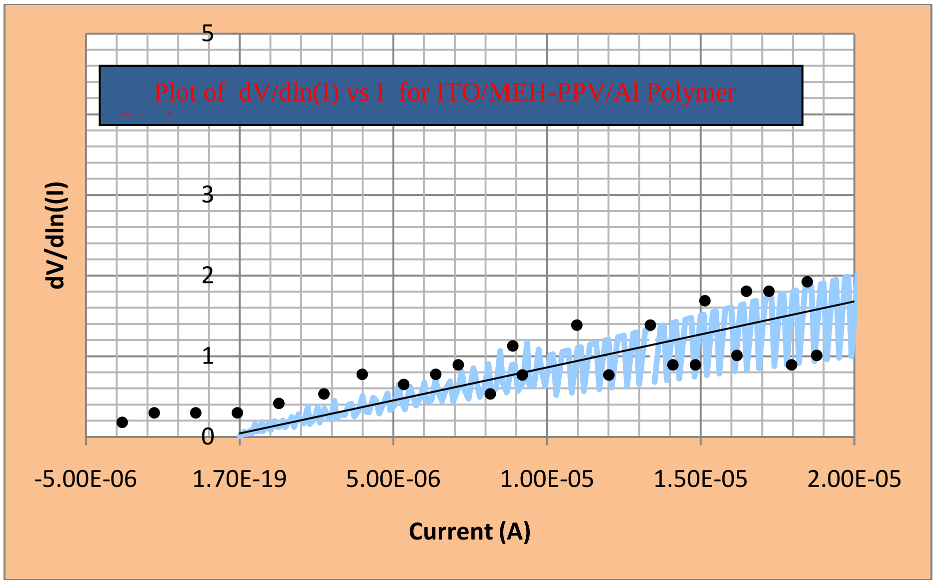

Figure 3. Plot of $\frac{dV}{dln(I)}$ vs. I for the ITO/MEH-PPV/Al diode.

The photoresponse on/off characteristics of ITO/MEH-PPV/Al diode under different illuminations for a voltage of 0.8 V on a timed scale (I-V-t) are shown in figure 4. The diode exhibits a good photoconductivity response and shows a sudden change as the light turns on. This behavior is abrupt and the increase is noticable in very short time, and the photocurrent under light shows a stable plateau value. The photocurrent was found to be 2.01 µA at 0.8 V for an optical power of 10 mW, where as the dark current was nearly 0.26 µA without light. Thus, the photocurrent was nearly 1.8 µA more than the dark current of the diode with the light on This shows that the photocurrent is drastically increased.

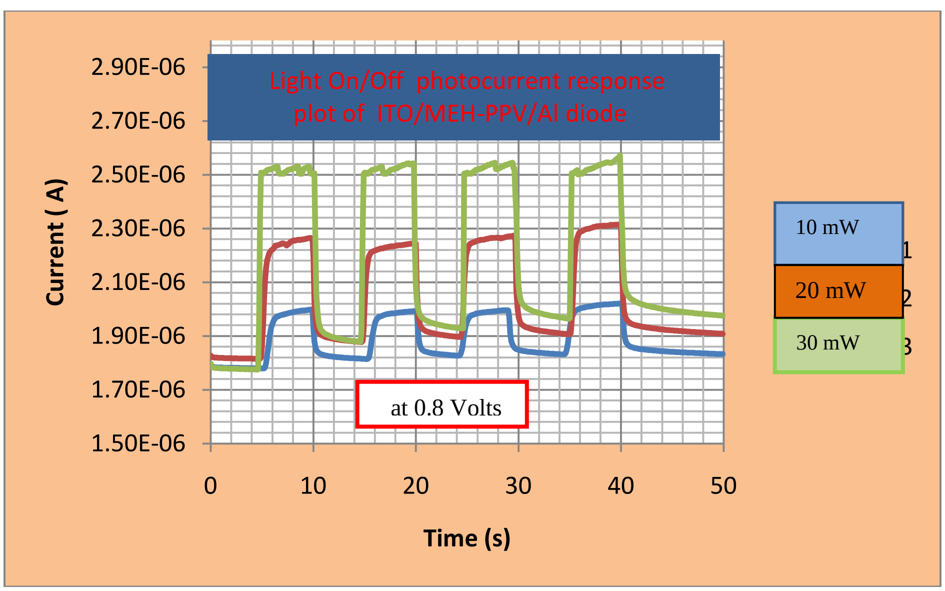

Figure 4. Plot of photocurrent time for a constant voltage (I-V-t) for the ITO/MEH-PPV/Al diode.

Figure 5 gives the photoresponsivity for various light intensities. In each case, the calculated responsivity was 2 x 10^{-4} A/W for a 10-mW light, 1.1 x 10^{-4} A/W for 20-mW light, and 0.8 x 10^{-4} A/W a 30-mW light. This indicates that the responsivity is decreasing as the power of the light is increased. However, to increase the photoconductive properties, one may use blended structures with fullerene or methanofullerene 6,6-phenyl C-61-butyric acid methyl ester (PCBM) as well as use additional light enhancement techiniques such as harnessing the plasmonic properties of silver or gold nanoparticles on the substrate.

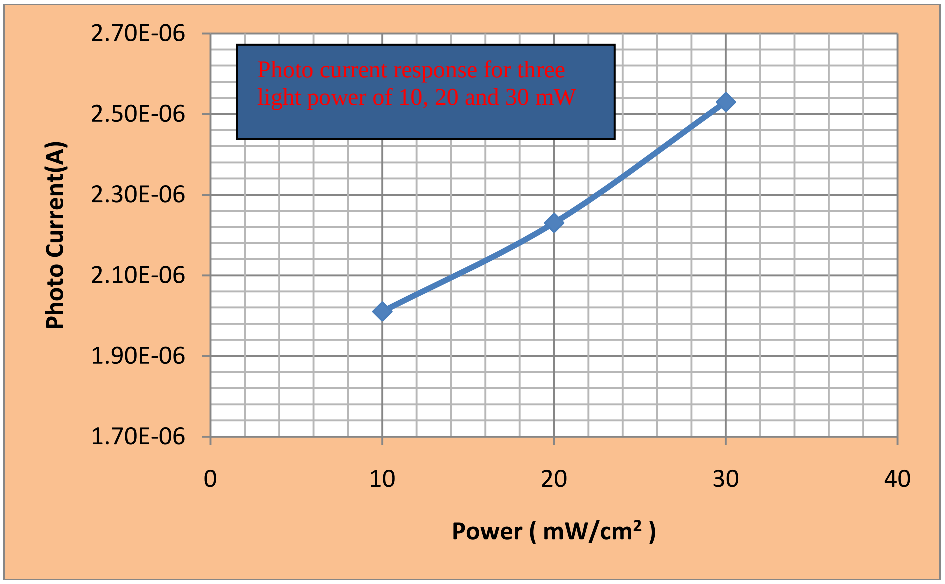

Figure 5. Plot of photocurrent vs. light intensity of the ITO/MEH-PPV/Al diode.

4. Conclusion

MEH-PPV was used with ITO as anode and Al as cathode to fabricate diodes. The fabricated devices were investigated for I-V characteristics and optical responsivity. The diode exhibited non-ideal behavior with an ideality factor of 0.85 eV. The I-V characteristics of the ITO/MEH-PPV/Al diode without light and with different illumination intensities give an open circuit voltage (V_{oc}) and a short circuit current of (I_{sc}). This result suggests that that this diode is photovoltaic under light illumination. Additionally, variations in the responsivity indicate that the ITO/MEH-PPV/Al device is a photo-sensitive diode. Studies of the electrical properties indicate that the photoconductive properties can be further improved by using blended materials (fullerene or PCBM) and incorporating plasmonic properties of silver or gold nanoparticles to enhance the absorption of light.

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